SUBMETERING TO EVALUATE ENERGY USE IN OFFICE BUILDINGS

PETER LARKAM
Engineer
Lower Colorado River Authority
Austin, Texas

ABSTRACT

The Lower Colorado River Authority (LCRA) has been collecting energy and demand data on its 75,000 square foot, five-floor Shapiro office building in Austin, Texas since June 1982. The building provides an ideal laboratory for studying energy-saving modifications because the major loads are metered individually. Sixteen submeters are used to monitor the computer mainframe, computer room HVAC, lighting, elevators, appliances, heating, and air conditioning.

The only way to accurately test the effectiveness of an energy savings modification is to isolate the associated energy consumption. Typically, energy conservation evaluations are based on energy (or demand) data from the metered total building, and changes in a specific load are obscured by unidentifiable load fluctuations within the building. Accurate knowledge of the energy consumption of individual loads (verified by measurement rather than predicted by theoretical calculations) can provide valuable insight into the design of more energy-efficient buildings.

INTRODUCTION

Energy is a vital and valued resource. To ensure efficient use of our energy resources, it is helpful to know how they are presently consumed. Although approximate energy consumption of various pieces of equipment can be calculated with information supplied by manufacturers, the most reliable way to determine precise energy consumption is to measure it. The LCRA in Austin has been monitoring energy and demand data within one of its 75,000 square foot, five-floor corporate office buildings since June 1982.

Fig. 1 Harry Shapiro Office Building

The Harry Shapiro office building at 3701 Lake Austin Boulevard in Austin was completed for occupancy in May 1982. During the initial design phase, interest was expressed in monitoring the consumption of energy within the building, and a decision was made to install two totalizing meters and sixteen submeters. The totalizing meters record the maximum thirty-minute demand as well as the cumulative kilowatt-hours. The submeters record discrete sub-level equipment consumption. Specifically, separate meters are used for the computer mainframe, the computer room air conditioning, the building lighting, elevators, appliances or office equipment, and air conditioning. All eighteen meters have been read monthly since June 1982. Results of the Shapiro Building energy audit program are presented in this paper.

SUBMETERING

Submetering is an important part of a complete energy audit. Only by metering each component separately is it possible to identify the cause of load fluctuations. For example, some loads such as air conditioning are highly sensitive to temperature. Others, such as elevators, are virtually unaffected by temperature. To observe the effect of temperature on energy consumption, it is necessary to meter the temperature-sensitive loads separately. Otherwise, observed load fluctuations due to temperature can be diminished or obscured by the relative stability of the temperature-independent loads.

The additional detail provided by a submetered energy audit has many uses. By metering lighting, for example, savings due to lower-wattage bulbs can be evaluated. In addition, mechanical or structural problems resulting in decreased energy efficiency are easier to isolate and identify in a submetered building. The results of an audit can also aid in making comparisons between various appliances and equipment. By calculating the energy consumed per square foot, one can compare the efficiency of different buildings.

METERING METHODS

Submetered demand and energy data may be collected either automatically or manually. Remote metering equipment can be employed to monitor energy consumption and to input the data directly into a computer-based system for analysis. However, while remote metering provides the most convenient method of data acquisition, the cost of metering equipment is high. Manual meter reading is equally reliable and less expensive, and meters may be read as frequently as needed for analysis. In order to meaningfully compare the energy consumption from

Proceedings of the Fifth Symposium on Improving Building Systems in Hot and Humid Climates, Houston, TX, September 12-14, 1988

different time periods, it is important that the time interval between meter readings be consistent. In the LCRA Shapiro audit, meters were read approximately each thirty days to ensure the desired consistency. All time periods shorter or longer than thirty days were adjusted to the thirty-day equivalent energy.

The eighteen watthour meters used in the energy audit are housed in the Shapiro Mechanical Room along with air conditioning compressors and pumps. Each meter displays the cumulative kWh, so monthly consumption is the difference between readings at the beginning and end of the month. All meters are labeled for ease in recording data. Figure 2 shows four meters attached to the west wall of the mechanical room.

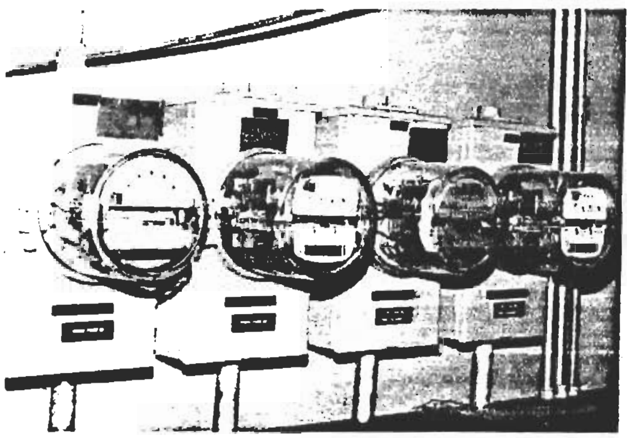


Fig. 2 Induction Watthour Meters

TERMS AND DEFINITIONS

Each of the eighteen watthour meters used in the LCRA Shapiro Building energy audit measures energy consumption. The two totalizing meters also record the maximum 30-minute, integrated demand via mechanical demand registers. Terms used in reporting the energy or demand findings are defined below:

DEMAND

The term "demand" has many possible meanings; as an electrical term, it should be defined specifically. The <u>American Standard Definitions of Electric Terms</u> states, "the demand of an installation or system is the load at the receiving terminals averaged over a specified interval of time."[1] In the case of variable loads, generally shorter time intervals are associated with higher demands. To be meaningful, a statement of demand must define the demand interval.

"The maximum demand of an installation or system is the greatest of all demands which have occurred during the specified period of time"[1] As with demand, a statement of the maximum demand must define the demand interval. In addition, it must define the period of time during which the demand was a maximum. Maximum demands can be hourly, daily, weekly, monthly, or annual.

Where several demands are reported simultaneously, the diversified or coincident demand is the demand of the entire group over a single time interval. The non-coincident demand is the sum of the demands in a group of loads with no restrictions on the interval to which each demand is applicable. Thus, the non-coincident demand is always equal to or greater than the coincident demand. Four different types of demand are reported in the Shapiro energy audit report. A brief description of each type follows:

<u>Maximum Demand</u>. Based on a 30-minute interval unless otherwise specified. With the totalizing meters, coincident-demand is reported.

<u>Annual Average kW Demand</u>. Total annual kWh divided by 8760 hours.

<u>Monthly Average kW Demand</u>. Total monthly kWh divided by 720 hours.

<u>Spot-check Demand</u>. The average demand over a very short (one-minute) interval obtained by counting disk revolutions on a meter and converting revolutions to kWh. The kWh is then divided by the time interval to get kW. If the load is constant and continuous over the entire month, the spot-check demand can be used as an estimate of the maximum demand. The formula for obtaining (spot-check) demand from disk revolutions follows:

$$kW = K_h \frac{[3600 \frac{seconds}{hour}][N\ revolutions][Multiplier]}{[1000 \frac{watts}{kW}][seconds\ in\ interval]} \quad (1)$$

where:

K_h = the disk constant, watthours/revolution,

N = number of disk revolutions during the time interval,

Mult. = specific multiplier for the meter, and

S = time interval, seconds.

LOAD FACTOR

"The load factor is the ratio of the average load over a designated period of time to the peak load occurring in that period."[1] The load factor indicates the degree to which the peak load is sustained during the period. Two load factors are reported in the energy audit:

<u>Annual Load Factor</u>. Annual average kW demand divided by maximum demand during the year. Maximum demand is the spot-check demand on submeters and the integrated 30-minute demand on the totalizing meters.

<u>Monthly Load Factor</u>. Monthly average kW demand divided by the maximum demand during the month. Maximum demand is the spot-check demand on submeters and the integrated 30-minute demand on the totalizing meters.

DATA ACQUISITION AND ANALYSIS

On the first day of each month (or the nearest Monday or Friday when the 1st was on a weekend), each of the LCRA energy audit meters was read. Original entries were made in a notebook with a separate page for each meter. Page headings included date, month, year, kWh dial reading, difference between readings, difference times multiplier, demand, and load factor. The notebook entries were then entered into a series of data files for analysis by SAS. The SAS program normalized the data to thirty-day months and output the final adjusted kWh for each month. SAS output was then input to the graphics program. The overall procedure is enumerated below:

1. Read meters
2. Enter data in notebook
3. Calculate number of days in time interval
4. Input to data files
5. Analyze with SAS
6. Transfer SAS output into graphics program

DESCRIPTION OF THE METERED LOADS

Sixteen loads are submetered within the Shapiro Building. Nine of these are grouped together to make up the Shapiro Building air conditioning and heating and four additional loads are grouped to total the computer room air conditioning. The remaining loads in the Shapiro Building are the elevators, the lights, and the wall receptacles and appliances.

TOTALIZING METERS

Computer Mainframe Equipment and UPS. Two IBM mainframe computers (3081-MVS, 4341-VM) and supporting hardware are powered by a backup power source. The uninterrupted power supply (UPS) is capable of powering the LCRA computers for approximately fifteen minutes. During normal operation, the computer equipment is powered by the UPS batteries which are simultaneously charged.

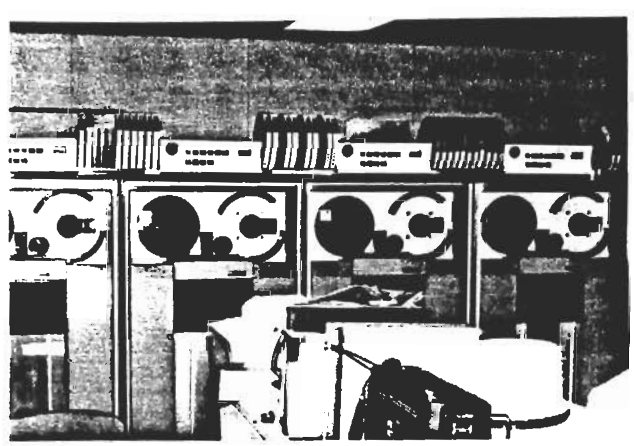


Fig. 3 Computer Tape Drives

The computer load has grown rapidly from 250.5 MWH in 1982 to 929.2 MWH in 1987. Most of the increased load is due to new equipment added to keep pace with LCRA's growing data processing needs.

Annual Maximum Demand for 1987:	126.0 kW
Annual Average Demand:	106.1 kW
Annual Load Factor:	0.84
Annual kWh per Square Foot:	337.88 kWh

Shapiro Main Power Bank. This meter is a total of all Shapiro loads which follow. The computer equipment is metered separately and is not included in the main power bank.

Annual Maximum Demand for 1987:	604.8 kW
Annual Average Demand:	382.1 kW
Annual Load Factor:	0.63
Annual kWh per Square Foot: (excluding computer)	46.32 kWh

The sum of the totalizing banks represents the entire Shapiro Building load. Figure 4 shows the history of total building load from 1982 through 1987.

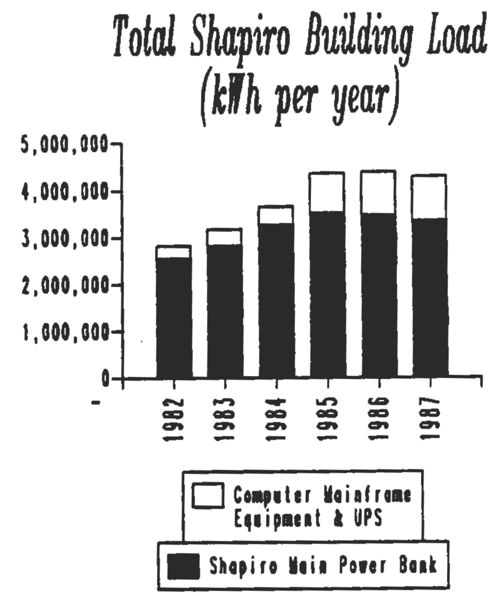


Fig. 4 Total Shapiro Building Load

SUBMETERS

Computer Air Conditioning. Two fifteen-ton EDPAC air conditioning units are metered with four meters. Initially, both units were installed in the computer room to cool the mainframe and peripheral equipment. In November, 1985, however, the second air conditioning unit was removed from service. The EDPAC unit was replaced by more sophisticated LIEBERT units mentioned below.

UNMETERED LOADS

An additional 35 tons of air conditioning is used to cool the computer mainframe and computer

Proceedings of the Fifth Symposium on Improving Building Systems in Hot and Humid Climates, Houston, TX, September 12-14, 1988

room. This load is metered under the Shapiro main power bank (750/ KVA 227/480 V transformer) but is not metered by an individual submeter. The unmetered computer air conditioning units are itemized below:

LIEBERT - 5 ton water chiller for IBM mainframe
LIEBERT - 10 ton A/C
LIEBERT - 20 ton A/C

Annual Average kW Demand for 1987: 37.3 kW

Figure 5 shows the components of the computer load and their growth from 1982 through 1987.

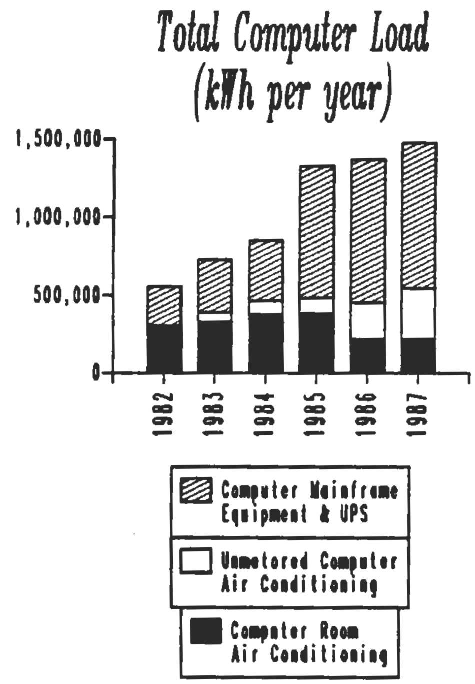


Fig. 5 Total Computer Load

AIR CONDITIONING AND HEATING

Air Handlers. Five blowers circulate the air in the Shapiro building and run continuously, drawing a load of approximately 54-60 kW. Maximum demand is unknown, but probably coincides with the spot-checked demand. The load factor is about 0.95. The horsepower and capacity of esch blower is tabulated below:

floor	horsepower	capacity (CFM)
first	15	11,000
second	25	16,000
third	25	16,000
fourth	25	16,000
fifth	25	18,000

The third floor air handling motor is shown in figure 6.

Main A/C Compressors. Three 75.3-ton TRANE air conditioning compressors are used for chilling in the summer. Two of these units are also used for heat recovery in the winter. The three compressors together draw a load which varies from 55 to 175 kW peaking in July or August.

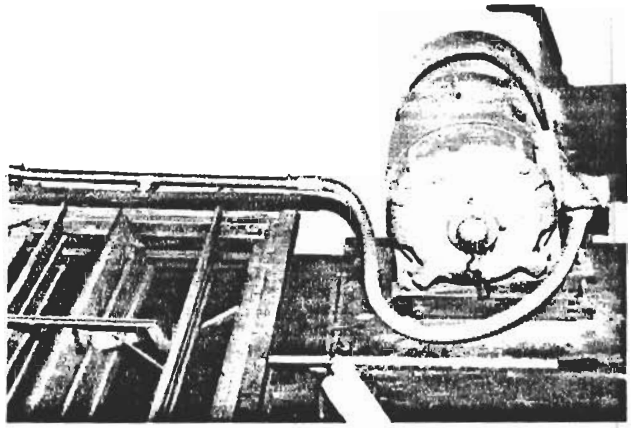


Fig. 6 Third Floor Air Handler Motor

Maximum Demand: Unknown
Annual Average Demand for 1987: 105.3 kW

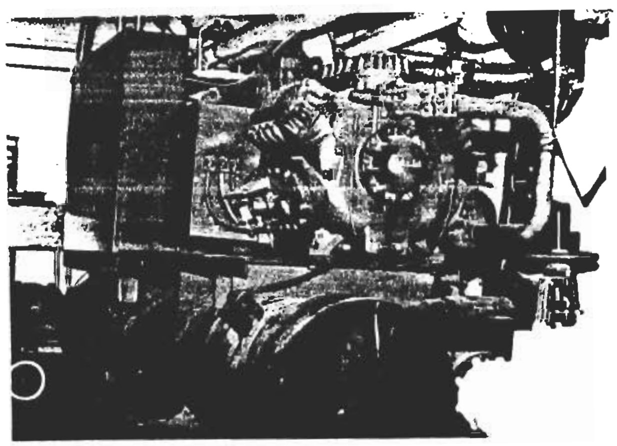


Fig. 7 Main A/C Compressor #3

Resistance Duct Heating. Resistance heating is occasionally used to supplement the Shapiro building heating in the winter. The average monthly demand varied from zero to 23 kW. Usage has generally declined since 1982.

Maximum Demand: Unknown
Annual Average Demand for 1987: 1.8 kW

floor	nameplate (KW)
first	27
second	29
third	29
fourth	29
fifth	32.5

River Water Pumps. Two twenty-horsepower motors draw water out of Lake Austin at 22 feet below the surface and pump it to the Shapiro

Proceedings of the Fifth Symposium on Improving Building Systems in Hot and Humid Climates, Houston, TX, September 12-14, 1988

mechanical room for use in the TRANE air conditioning condensers. The cycled water is then returned to the lake. Unlike most air conditioning compressors which use air as a heat source or sink, the LCRA Shapiro compressors use lake water for this purpose. The pumps draw a combined load of between 10.75 and 23 kW.

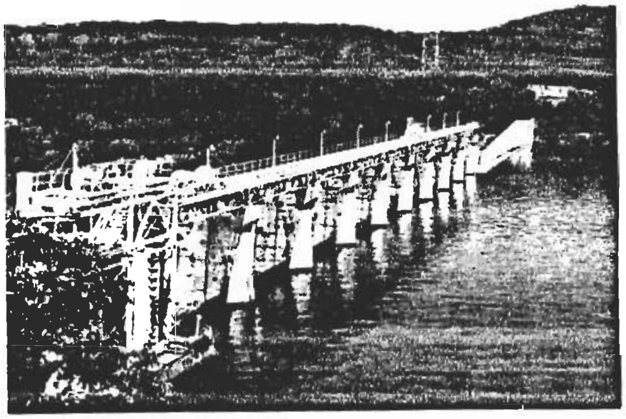


Fig. 8 LCRA's Tom Miller Dam on Lake Austin

Maximum Demand: Unknown
Annual Average Demand for 1987: 19.0 kW

Circulating Water Pumps. Two pumps are used to circulate water in the Shapiro Building for heating and cooling. The hot pump is a 7.5-hp Dayton rated at 1745 rpm and the cold pump is a 15-hp Toshiba rated at 1755 rpm. The meters on these pumps were originally installed incorrectly. Both pumps run continuously (load factor of unity) and have a combined load of 15-17 kW. The pump are shown in figure 9 below:

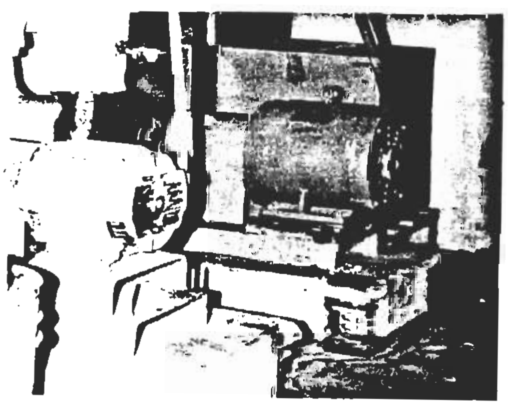


Fig. 9 Circulating Water Pumps

Elevators. Three Montgomery Elevators with an annual average demand of 4.7 kW serve the Shapiro Building occupants. Each elevator is powered by a 50 hp hydraulic pump operating at 1760 rpm and rated for a maximum of 80 starts per hour. The spot-check demand is 35 kW.

Lighting. The fluorescent lighting in the Shapiro Building has a spot-check demand of 170 kW, and an average demand of 70-85 kW. The maximum demand is not known but probably coincides with the spot-checked demand. In this case, the load factor is 0.45.

Wall Receptacles and Appliances. A dry-type transformer on each floor serves copy machines, typewriters, computer terminals, and appliances. Average monthly demand has steadily increased from 20 kW in 1982 to 42 kW in the spring of 1987. The average Annual Demand for 1987 was 39.2 kW. Maximum demand is unknown.

Figure 10 shows the contribution of each of the above loads to the total Shapiro Building load.

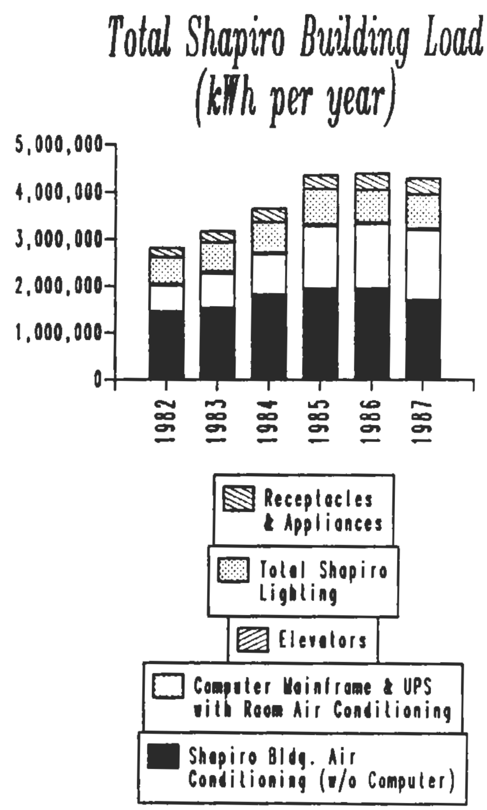
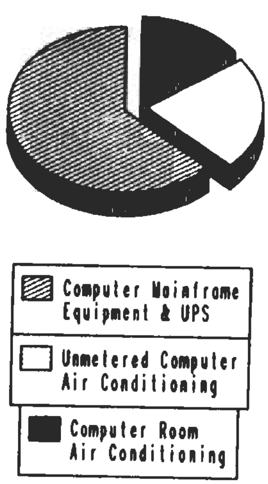


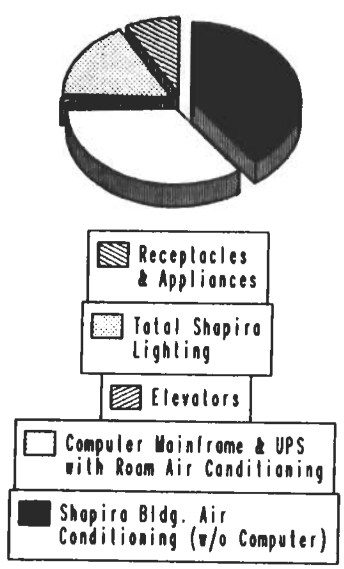
Fig. 10 Total Shapiro Building Load

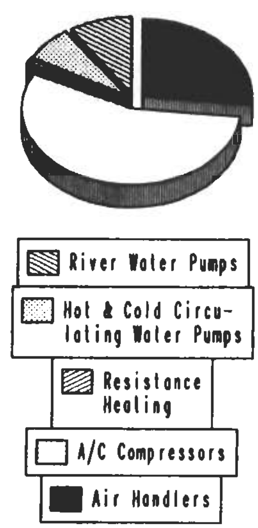
[1] American Standard Definitions of Electrical Terms, Group 35, Generation,Transmission, and Distribution, ASA C42.35 - 1957.

SHAPIRO ENERGY AUDIT
PERCENT ENERGY USED (KWH)

SHAPIRO EQUIPMENT / YEAR	1982	1983	1984	1985	1986	1987
MAIN POWER BANK	91%	89%	89%	81%	79%	78%
MAINFRAME	9%	11%	11%	19%	21%	22%
SHAPIRO TOTAL	100%	100%	100%	100%	100%	100%
AIR HANDLERS	33%	33%	28%	26%	24%	28%
A/C COMPRESSORS	49%	47%	54%	60%	62%	54%
RESISTANCE HEATING	1%	4%	1%	1%	0%	1%
CIRCULATING PUMPS	9%	9%	8%	7%	7%	8%
RIVER WATER PUMPS	8%	8%	8%	6%	7%	10%
SHAPIRO A/C	100%	100%	100%	100%	100%	100%
FDPAC A/C	52%	45%	44%	29%	16%	15%
UNMETERED A/C	3%	8%	10%	7%	17%	22%
MAINFRAME	45%	46%	45%	63%	67%	63%
COMPUTER TOTAL	100%	100%	100%	100%	100%	100%
ELEVATORS	4%	4%	4%	4%	3%	4%
LIGHTING	70%	70%	67%	69%	64%	65%
APPLIANCES	26%	26%	29%	27%	32%	31%
SHAPIRO WITHOUT A/C	100%	100%	100%	100%	100%	100%
SHAPIRO A/C	52%	49%	50%	45%	45%	40%
COMPUTER TOTAL	20%	23%	23%	30%	31%	34%
ELEVATORS	1%	1%	1%	1%	1%	1%
LIGHTING	20%	20%	18%	17%	15%	17%
APPLIANCES	7%	7%	8%	7%	8%	8%
SHAPIRO TOTAL	100%	100%	100%	100%	100%	100%







Proceedings of the Fifth Symposium on Improving Building Systems in Hot and Humid Climates, Houston, TX, September 12-14, 1988

SHAPIRO ENERGY AUDIT
ANNUAL KWH (8760 HOURS)

SHAPIRO EQUIPMENT / YEAR	1982	1983	1984	1985	1986	1987
MAIN POWER BANK	2568301	2826955	3262185	3509462	3465797	3346968
MAINFRAME	250480	338185	384412	839413	913425	929160
SHAPIRO TOTAL	2818781	3165140	3646597	4348875	4379222	4276128
AIR HANDLERS	478600	502768	517663	508005	476544	473664
A/C COMPRESSORS	712259	730953	992994	1164956	1206646	922335
RESISTANCE HEATING	18771	54980	20827	18728	5848	15778
CIRCULATING PUMPS	138092	136512	138092	138092	138337	131211
RIVER WATER PUMPS	115319	119621	154918	126675	128215	166065
SHAPIRO A/C	1463041	1544834	1824494	1956456	1955590	1709053
EDPAC A/C	287367	329158	377533	384046	218311	219064
UNMETERED A/C	17653	60076	88560	99185	234897	326548
MAINFRAME	250480	338185	384412	839413	913425	929160
COMPUTER TOTAL	555500	727419	850505	1322644	1366633	1474772
ELEVATORS	34611	35300	38902	38057	36867	41414
LIGHTING	556584	628510	652263	740331	677844	707935
APPLIANCES	208775	229077	280433	291387	342288	342954
SHAPIRO WITHOUT A/C	799970	892887	971598	1069775	1056999	1092303

SHAPIRO ENERGY AUDIT
ANNUAL AVERAGE KW DEMAND

SHAPIRO EQUIPMENT / YEAR	1982	1983	1984	1985	1986	1987
MAIN POWER BANK	293.2	322.7	372.4	400.6	395.6	382.1
MAINFRAME	28.6	38.6	43.9	95.8	104.3	106.1
SHAPIRO TOTAL	321.8	361.3	416.3	496.4	499.9	488.1
AIR HANDLERS	54.6	57.4	59.1	58.0	54.4	54.1
A/C COMPRESSORS	81.3	83.4	113.4	133.0	137.7	105.3
RESISTANCE HEATING	2.1	6.3	2.4	2.1	0.7	1.8
CIRCULATING PUMPS	15.8	15.6	15.8	15.8	15.8	15.0
RIVER WATER PUMPS	13.2	13.7	17.7	14.5	14.6	19.0
SHAPIRO A/C	167.0	176.4	208.3	223.3	223.2	195.1
EDPAC A/C	32.8	37.6	43.1	43.8	24.9	25.0
UNMETERED A/C	2.0	6.9	10.1	11.3	26.8	37.3
MAINFRAME	28.6	38.6	43.9	95.8	104.3	106.1
COMPUTER TOTAL	63.4	83.0	97.1	151.0	156.0	168.4
ELEVATORS	4.0	4.0	4.4	4.3	4.2	4.7
LIGHTING	63.5	71.7	74.5	84.5	77.4	80.8
APPLIANCES	23.8	26.2	32.0	33.3	39.1	39.2
SHAPIRO WITHOUT A/C	91.3	101.9	110.9	122.1	120.7	124.7

ANNUAL KWH PER SQUARE FOOT

SHAPIRO TOTAL (75,000 SQ. FT.)	37.58	42.20	48.62	57.99	58.39	57.02
SHAPIRO A/C (72,250 SQ. FT.)	20.25	21.38	25.25	27.08	27.07	23.65
COMPUTER TOTAL (2750 SQ. FT.)	202.00	264.52	309.27	480.96	496.96	536.28

MAXIMUM 30-MINUTE INTEGRATED DEMAND
AND ANNUAL LOAD FACTOR

COMPUTER	35.40	50.40	84.96	133.92	133.20	126.00
LOAD FACTOR	0.81	0.77	0.52	0.72	0.78	0.84
MAIN POWER BANK	508.80	571.20	590.40	727.20	842.40	604.80
LOAD FACTOR	0.58	0.56	0.63	0.55	0.47	0.63